CHARACTERISTICS OF FREQUENCY DOMAIN SPECTRUM OF SELF-NULLING EDDY CURRENT PROBE OUTPUT

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INTRODUCTION

Since its introduction several years ago, the self-nulling eddy current probe [1-3] technology has been one of the focal points of the aging aircraft related R&D effort. Numerous application areas have broadened the scope of the probe which has also helped in better understanding the underlying principle. As the technology matures, however, deeper understanding on the various details related to the self nulling effect is needed to overcome difficulties associated with the current field tests and expand its application areas. A particular problem to be addressed is in differentiating the effect of small, shallow surface cracks from that of probe wobble during automated data acquisition operation.

The role of the flux focusing lens to the self-nulling effect is well known through a series of experiment [4] and numerical modeling [5,6] studies. All the previous investigation, however, has been limited to several discrete values of the operating frequencies merely to provide a snapshot of the magnetic flux distribution. Since the goal is to gain deeper insight into the basic phenomenon, the present study first investigates on the probe output characteristics as a continuos function of the frequency.

BACKGROUND

Previous publications [1-6] have detailed the basic characteristics of the self nulling probe, application to crack detection and thickness gauging in aluminum structures. Fig. 1 shows the schematic of the self-nulling probe. The probe has an exciter and pick-up coil separated by a flux focusing lens or shield. Typical material used for the lens is 1020 steel or mumetal. The operating frequency in the self nulling mode is dependent on the probe

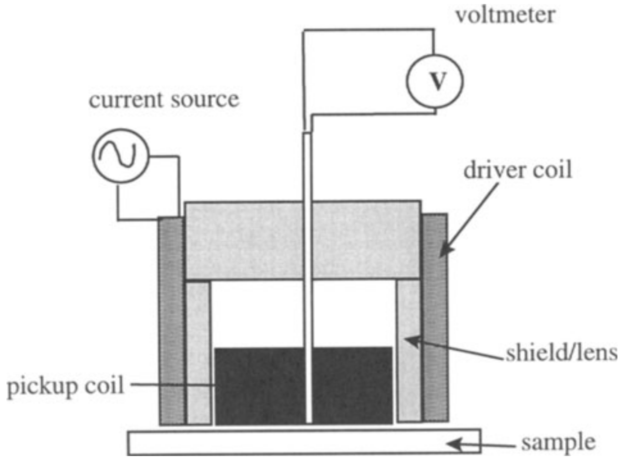

Fig. 1 Schematic of the self nulling probe design

lens/shield diameter, the number of turns, the shield material etc. Typical frequency has been from 70 Khz to 200 Khz with probe lens diameter varying from 25 mm to 3 mm. At the resonant frequency, when the probe is placed over a good conductor the pickup coil voltage reduces to zero, thus producing the null voltage. As the frequency is lowered, the null condition is not satisfied, which is then used for estimating the thickness of aluminum and other non magnetic materials [3]. In the next section the lift-off characteristics of the probe is studied over a wide frequency range.

LIFT- OFF CHARACTERISITICS

One of the major issues that need to be better understood is to differentiate the signal between a shallow crack and probe wobble or lift-off. This implies that the signal to noise ratio for partially through cracks has to be improved for increased detectability. Fig. 2 shows the lift-off curves for a probe operating from near DC to 300 Khz with a resonant peak at around 140 Khz while Fig. 3 is a plot from DC to 100 KHz. The plots clearly indicate a large difference between the output voltage for a lift-off of 0.5 mm (.020") and 1.25 mm (.050") on an aluminum block without a crack.

An interesting plot of the output voltage of the pickup coil for lift-off of 0.25 mm (0.010") over a thin aluminum block without any cracks is shown in Fig. 4. The key features in this plot is the two peaks in the output voltage with and without lift-off. The second peak is due to the resonant frequency of 140 KHz, while the first peak occurs around 20 Khz. At this frequency the skin depth in the steel shield or the mumetal shield is so small that there should be no direct magnetic field linking both the coils. The authors feel that this peak is a combination of the penetration of the magnetic field through the shield/lens and twice through the aluminum block. It is this phenomenon that needs to be studied further.

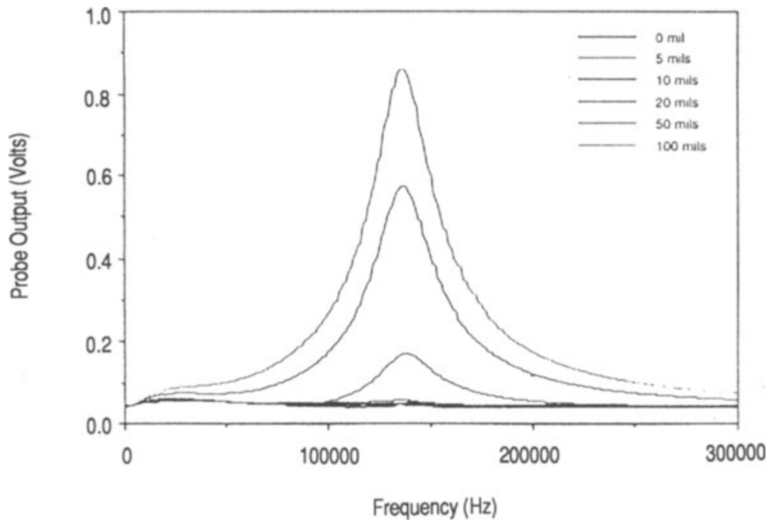

Fig. 2. Lift-off characteristics for the self nulling eddy current probe over an aluminum block.

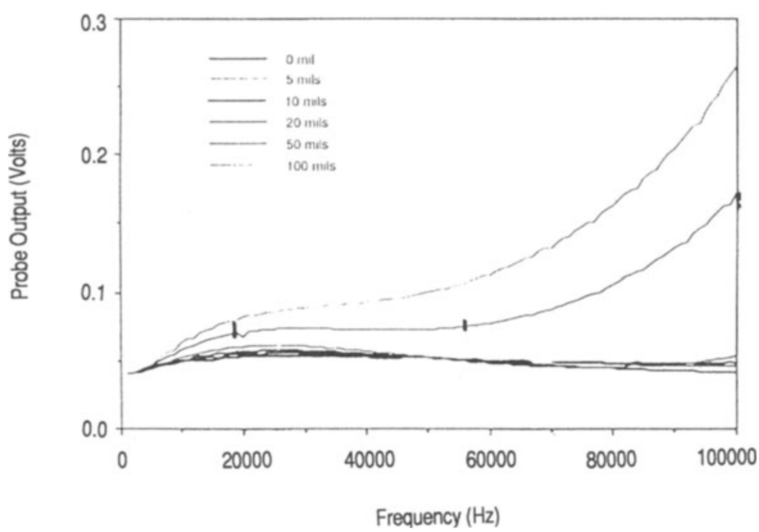

Fig. 3. Lift-off characteristics for the self nulling eddy current probe over an aluminum block.

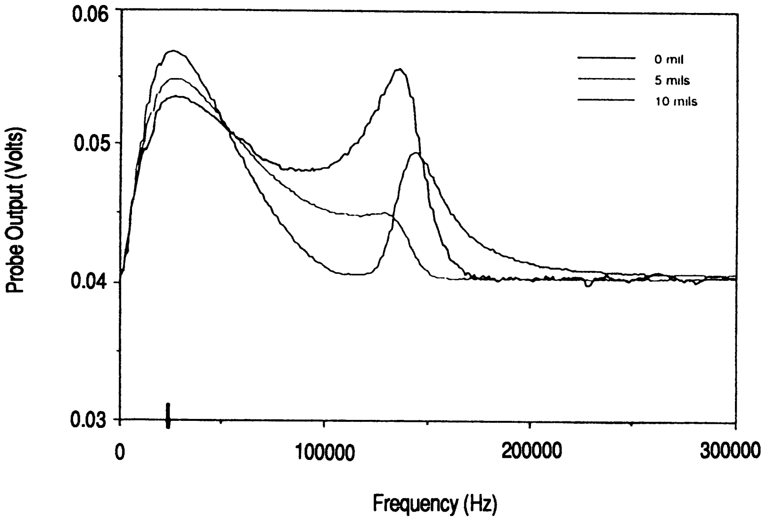

Fig. 4 Probe output voltage for the self nulling eddy current probe over a thin aluminum block without a crack for lift-off from 0 mm to 0.25 mm (0.010").

One of the methods chosen to better understand is to use the finite element modeling (FEM) technique to visualize the magnetic flux distribution around the probe and the sample for different lift-off and frequency. The following section details the FEM data for a given probe configuration.

FINITE ELEMENT MODELING

An axisymmetric FEM for a given probe was developed with a view to visualize the magnetic flux distribution and compute the pickup coil voltage. All the dimensions and material properties in the model were very similar to the experimental situations. Fig. 5 fig.6 and fig. 7 display the flux distribution in the shield, the aluminum block and the space around for the probe with no lift-off for different frequencies. Due to symmetry only one half of the geometry is modeled.

One can observe from all these three plots the penetration of the flux into the material and the shield as the frequency is lowered. At 10 Khz and 1 Khz there is a significant penetration of the magnetic flux under the pickup coil region, which will produce a voltage output for the probe. At 50 Khz the component of the flux leaking in under the pickup coil is absent. Additionally the number of flux lines in the shield is also much higher at 1 Khz and 10 Khz as compared to 50 Khz. This direct flux linkage is another component that will produce a probe output voltage at lower frequency. These plots are part of the explanation for producing the peak voltage at a lower frequency in the lift-off characteristics in fig. 3.

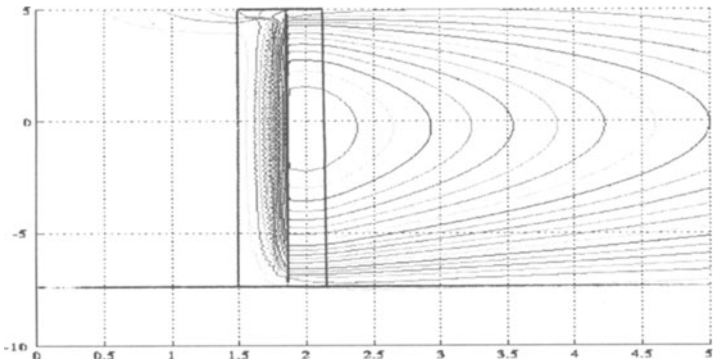

Fig. 5. Finite element simulated magnetic flux distribution for the self nulling eddy current probe at 50 Khz

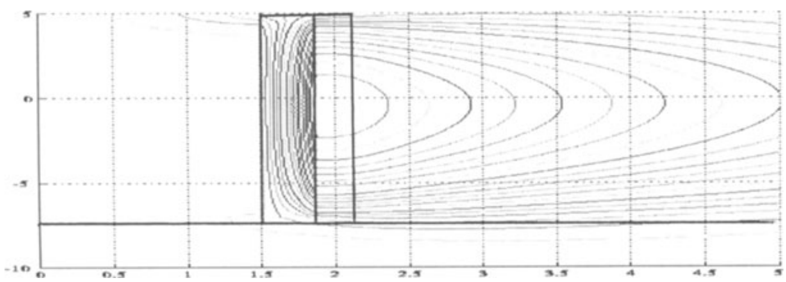

Fig. 6 Finite element prediction of the flux distribution of the self nulling eddy current probe at 10 Khz

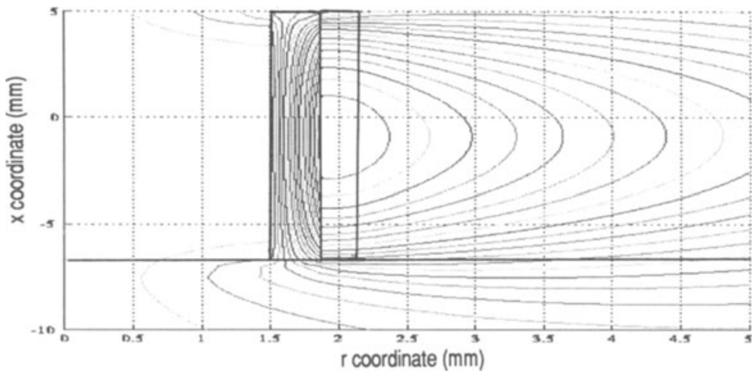

Fig. 7 Finite element prediction of the flux distribution of the self nulling eddy current probe at 1 Khz

A theoretical study to understand the eddy current distribution in the material or sample and the interaction of the eddy current with a crack has been presented in a previous publication [6]. This technique uses a combination of the complex variable analysis with the finite element method to produce the current stream lines due to the probe and its distribution when these lines are interrupted by crack. The figures clearly indicate the eddy current distribution for a crack smaller than the probe diameter and for one longer than the probe dimensions. It is the presence of the eddy current distribution underneath the pickup coil that gives rise to the normal component of the magnetic field which produces the probe output voltage.

The FEM results in conjunction with the above theoretical study has thrown more light on the behavior of the probe at different frequency. One can explain the probe output voltage at low frequencies and how one could use it for thickness gauging. The phenomenon that needs to be resolved is the difference in the signal due to lift-off or probe wobble and a shallow crack.

Fig. 8 shows the lift-off characteristics of the probe for an aluminum sample with an EDM notch. Comparing the output voltage in fig. 8 with that in fig. 2 and 3, there is one stark difference. The voltage in fig. 8 is increasing linearly with frequency while for the crack free case, this is not true. In thin materials there is a significant peak present at low frequency, while for thicker materials the rate of increase is slower. Thus one could account for this difference very easily using some simple mathematical technique during routine inspection.

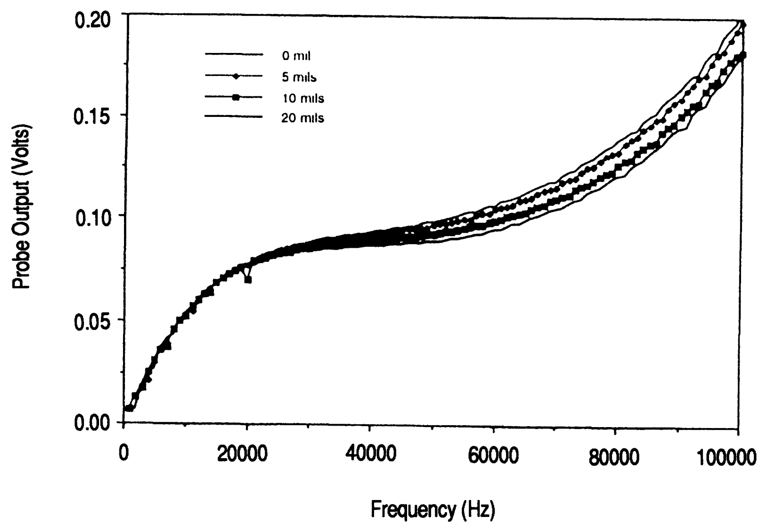

Fig. 8 Lift-off characteristics of the self nulling eddy current probe for an aluminum sample with an EDM notch.

CONCLUSIONS

This paper dealt with the frequency characteristics of the self nulling eddy current probe in an attempt to distinguish between the probe wobble or lift-off signal and the signal due to a shallow crack. Experimental data in conjunction with theoretical analysis was used to understand the behavior of the probe.

The lift-off curve on a sample with an EDM notch seem to show a linearly increasing trend as opposed to the curve for a sample without a defect. This trend was consistent for a number of different samples and cracks in aluminum. Thus, one can exploit this difference to distinguish the probe output voltage between probe wobble and shallow cracks.

REFERENCES

1. B. Wincheski, J.P. Fulton, S. Nath , M. Namkung and J.W. Simpson, "Self-Nulling Eddy Current Probe for Surface and Subsurface Flaw Detection," in *Materials Evaluation*, Vol. 52/Number 1 (January 1994)
2. M. Namkung, C.G. Clendenin, J.P. Fulton and B. Wincheski, *Review of Progress in QNDE*, Vol. 13B, 1633, Plenum Press, New York, 1994.
3. J.P. Fulton, B. Wincheski, S. Nath, J. Reilly and M. Namkung, Review of Progress in QNDE, Vol. 14B, 2317, Plenum Press, New York, 1995.
4. B. Wincheski. J. P. Fulton, R. Todhunter and J. Simpson, Reveiw of Progress in QNDE, Vol. 15B, 2133, Plenum Press, New York, 1996.
5. S. Nath, R. Wincheski, J. P. Fulton and M. Namkung, "Study of the New Eddy Current Nondestructive Testing Sensor on Ferromagnetic Materials," in *IEEE Trans. Mag.* Nov 1994.
6. B. Wincheski, J. P. Fulton, S. Nath and M. Namkung, Review of Progress in QNDE, Vol. 14 A, 291, Plenum Press, New York, 1995.